Z was the last introduced of the letters of the Roman alphabet. * * * It crept into English during the fifteenth century from the French, and in use is now pretty nearly restricted to foreign loan-words * * * *çedilla* means *little zed: zediglia* is the diminutive for *zeticula.*" p. 138.

The Microscopic Examination of Timber with regard to its Strength. A Contribution from the Eli K. Price Botanical Laboratory of the University of Pennsylvania. By Frank M. Day.

(*Read before the American Philosophical Society, December 21, 1883.*)

The valuable paper of Dr. J. T. Rothrock upon "Some Microscopic Distinctions between Good and Bad Timber of the Same Species," recently read before the American Philosophical Society, has opened a broad field for original investigation. The question there suggested as to the possibility of approximately determining the strength of timber by microscopic examination (involving as it does the question of the "differences in the strength of wood due to the molecular differences in the structure of the fibre") is one that can be answered only after the most extended and carefully conducted investigation.

As long as we confine ourselves to the examination of various specimens of the same species the task of distinguishing the good pieces from the bad, and of roughly predicting the relative strains which they will resist, is comparatively easy.*

Plate I showing transverse sections of two pieces of Rock Elm (*Ulmus racemosa* Thomas), furnishes illustrations of the general differences between good and bad wood of the same species. The upper figure is a section of the wood used by a well-known firm in their highest grade of hubs; the lower is a section of wood which they declare to be practically worthless. It is evident from a glance at these drawings that the good differs from the bad, in 1st, The much smaller area occupied by ducts; 2d, The smaller bore and consequently thicker walls of the woody fibres; 3d, The more compact arrangement of the woody fibres, giving them a polygonal rather than a circular outline; 4th, The much greater annual growth. These are the elements which it is but reasonable to suppose would give strength to the wood. They are further those which are found to do so in the great majority of cases.

The strength of the cellulose of which the wood is composed, is, in various species and under various conditions, by no means the same. For example, Buttonwood (*Platanus occidentalus* L.) rapidly loses the greater part of its strength, by a natural process which the woodsmen call "doating," the only indication of which is a bleaching of the tissues. Hence any statements as to the strength of timber, made from an examination of the structure alone are open to question.

* This it will be urged can be done by the practical eye without the aid of the microscope, but it must be remembered that the entire investigation of the subject is, at its present stage, of theoretical rather than practical interest.

We are, however, able to leave this uncertain element out of consideration when we turn our attention to the following experiments upon the transverse strength of the coniferous woods, the results of which point to an almost identical value for the strength element of the cellulose in the several pieces tested. Each piece was exactly one-and-a-half inches square by two feet nine inches long, and rested upon rounded edges at a distance of two feet six inches apart. The pressure was gradually applied at a point half way between the supports, and the deflection was taken at each hundred pounds.

Plate II shows, side by side, transverse sections of three pieces thus tested. The detail of the experiments are exhibited in the following table :

Letter of Experiment.	NAME OF WOOD.	Specific Gravity.	Greatest Strain	Effect of Greatest Strain.	Deflection with Greatest Strain	Deflection with 500 lbs.	Length of Woody Fibre.	Average Annual Growth.
			Lbs.		In.	In.	In.	In.
H	Yellow Pine (*Pinus* sp ?)	.817	2000	Broke.	.84	.20	.165	.125
L	White Pine (*Pinus Strobus* L.)	.415	1190	Broke.	1.21	.43	.169	.033
E	Hemlock (*Abies Canadensis* Michx.).	.422	1000	Broke.	.98	.36	.176	.071

These results, taken in connection with an examination of the sections, indicate a great probability that in the coniferous woods the strength depends chiefly upon the ratio of the number of thickened autumn-fibres to the total number of fibres formed during the year, becoming greater the greater the number of thickened fibres. Thus it is seen that in *H*, by far the strongest of the three pieces tested, the thick-walled fibres occupy almost half the year's growth, while in *E* they form a mere strip at the end of the growth. In connection with this statement it may be well to remark that the absolute breadth of the annual growth in the coniferous woods does not seem to be as important an element in the problem of strength as in the so-called "hard-woods" (*Angiosperms*). The reason of this is the absence of the ducts which in the "hard woods" are formed, as a rule, in the early part of the annual growth. After this the solid wood is formed. Hence, the value in them, other things being equal, of a large annual growth.

The ease with which the results of the tests upon the coniferous woods are explained gives place to the greatest difficulty in the case of the hard woods. Important factors in this case, and ones which we have not been called upon to consider in the coniferous woods, are, 1st, the weakness due to a greater or less abundance of ducts, and second, the strength added by more or less highly developed medullary rays.* The following table contains the results of eight experiments as to transverse strength made in exactly the same manner as described in the previous case. The pieces of timber were in all cases carefully selected and accurately dressed. They

* The medullary rays being much less conspicuous in the Coniferæ.

were free from shakes and all other imperfections that might tend to vitiate the results :

Letter of Experiment.	NAME OF WOOD.	Specific Gravity.	Greatest Strain. lbs.	Effect of Greatest Strain.	Deflection of Greatest Strain.	Deflection with 500 lbs. in.	Length of Woody Fibre. in.	Exterior Diameter of Woody Fibre. in.	Interior Diameter of Woody Fibre. in.	Ratio of Exterior to Interior Diameter.	Duct Area. sq in	Average Annual Growth. in.
A	Hickory (Carya porcina, Nutt.)................	.609	1600	Broke.	1.52	.17	.057	.000811	.00036	2.25	.177	.040
B	Hickory (Carya porcina, Nutt.)................	.966	1400	No sign of Breaking.	4.59	.22	.048	.000576	.00012	4.82	.029	.125
D	White Oak (Quercus alba, L.)................	.706	1500	Broke.	1.08	.40	.056	.000696	.000312	2.23	.189	.047
C	White Oak (Quercus alba, L.)................	.825	1200	No sign of Breaking.*	4.56	.46	.055	.000699	.000216	3.22	.048	.107
G	White Ash (Fraxinus Americana, L.)...........	.615	1750	Broke.	1.08	.29	.047	.000904	.000488	1.85	.222	.052
I	Red Ash (Fraxinus pubescens, Lam.)...........	.669	1600	Broke.	1.28	.36	.059	.000888	.000512	1.71	.253	.055
J	Chestnut (Castanea vesca, L.)................	.441	900	Broke.	.55	.49	.042	.00104	.000784	1.33	.210	.066
K	Tulip Poplar (Liriodendron Tulipifera, L.)......	.414	1200	Broke.	.94	.24	.053	.001176	.000768	1.53	.333	.051

*Stick bent to support. Hence could bend no further.

Each of the numbers given in the columns headed, Length of Woody Fibre, Exterior Diameter of Woody Fibre and Interior Diameter of Woody Fibre is the average of twenty micrometric measurements. The numbers in the column headed Duct Area represent the area occupied by ducts in one square inch of transverse section. Each of the results there given is the average of planimeter measurement of three camera lucida drawings taken at various parts of a section.

The results of the first four of the above experiments may be summed up thus : *A* and *D stiff* hickory and white oak had small annual growth, moderately large duct area and moderately thick fibre walls ; whereas *B* and *C*, *elastic* hickory and white oak, had moderately large annual growth, small duct area and thick fibre walls. Whether the general difference between elastic and stiff timber is chiefly due to a difference in the character of the cellulose, or whether it is chiefly due to a difference of cell structure is a question that would require a much more extended series of experiments than the above to settle finally. The results given, though too few in number to be of great value, point to the latter view of the case ; while the fact that the same piece of wood will, at various ages, exhibit various degrees of elasticity, inclines us to the former. The experiments *G*, *I*, *J* and *K* show the difficulty of comparing woods of different species. For instance, the pieces *G* and *J* had almost the same annual growth, duct area and fibre thickness. Yet they broke with strains of respectively 1750 lbs. and 900 lbs. An observation that brings out more clearly than before the fact that *differences* of *strength* in woods of *different species* are largely due to *differences* in the *cellulose*.

The measurements of length of woody fibre given in this and in the table of the results of experiments upon the coniferous woods, furnish excellent proof of the correctness of the statement made by Dr. Rothrock, that the relation between the absolute length of fibre and the strength of timber is a very slight one.

The importance of the medullary ray as a strength giving element, though suggested, has not, heretofore, been insisted upon with sufficient positiveness. The following experiments, undertaken with reference to this point, show that in woods such as Oak and Buttonwood, in which the rays are highly developed, a large part of the strength is due to their presence. From cubes of wood, the edges of which measured six inches, plates six inches square and one inch thick were cut in a direction transverse to the woody fibres. From these, pieces of a shape suitable for testing in a cement testing machine were cut, in such a manner that half of the pieces had he medullary rays running in the direction in which the tension was applied, and half of them in a direction perpendicular to this. In each the area subject to strain was one square inch. The result gives, of course, the lateral adhesion of the fibres, with and without the strength added by the medullary rays.

	Live Oak, (*Quercus virens*, Ait.)	Red Oak, (probably either *Q. rubra* or *Q. palustris.*)
	Lbs.	Lbs.
The five pieces tested with the rays running in the direction of the tension broke at..	1265 900 1250 960 1225	440 490 480 425 470
Average........	1120	461
The five pieces tested with the rays running perpendicular to the direction of tension broke at....................	500 710 480 590 680	245 195 155 190 160
Average........	592	189

The surprising fact will be observed that in the Live Oak the force required to overcome the lateral adhesion of the fibres when reinforced by medullary rays is almost, and in the Red Oak more than twice that required when not so reinforced. Similar experiments upon Buttonwood (*Platanus occidentalis*, L.) would probably show an equal, if not greater, difference. While Hemlock, Pine, Tulip-Poplar or other woods with weak rays, it is but reasonable to expect, would show but slight differences in the two directions.

In view of the above results it is easy to see that resistance to splitting, although usually ascribed to "crookedness of grain," is also in a large measure due to the binding action of the rays. Where, however, we have both of these qualities present, we find a wood admirably adapted for certain purposes, as for example the manufacture of hubs. Hence it is that Rock Elm (*Ulmus racemosa*) and Black Gum or Tupelo (*Nyssa multiflora*, Wang.), in both of which abundant rays are found coupled with great contortion of fibres, are much in demand by hub makers.

In Lignum Vitæ (*Guaiacum officinale*) the crossing of the fibres of different layers is very apparent, and in a specimen of Black Gum, fibres were found which deviated from the vertical as much as ten times their breadth in their own length.

Plates III and IV are given as illustrations of the statement concerning the resistance to splitting or wedging made above. The upper half of Plate III shows a transverse section of Buttonwood, enlarged 125 times. The drawing is made from the wood of the butt of a tree which portion presented such great resistance to wedging that it was finally reduced to manageable size by the use of gunpowder. In it are seen the abundance

of ducts and great size of medullary ray characteristic of this wood. Below it is placed a transverse section of Tulip-Poplar (same amplification), a wood which splits as easily as Pine. In it the abundance of ducts and weakness of medullary rays are shown. Plate IV gives the same woods, with the same amplification in tangential section, thus cutting the rays transversely and showing the contortion of the fibres in Buttonwood and their straightness in Tulip-Poplar.

To Dr. J. T. Rothrock, for his kind assistance and advice during the preparation of the present article, the writer wishes to express his sincerest thanks. Thanks are also due to Mr. Simmonds, of the University, for his careful preparation of the specimens tested, and to Messrs. Riehlé Bros., upon whose machines the work of testing was performed.

Explanation of Illustrations.

The drawings were all made by the aid of the camera lucida.
In Plate II the amplification is 75 diameters.
In Plate I, III and IV the amplification is 125 diameters.

Plate I, *a*, *Ulmus racemosa.* (Good.)
b, *Ulmus racemosa.* (Bad.)

Plate II, *a*, *Pinus* (sp. ?)
b, *Abies Canadensis.*
c, *Pinus Strobus.*

Plate III, *a*, *Platanus occidentalis*, *b*, *Liriodendron Tulipifera*, } Transverse sections.

Plate IV, *a*, *Platanus occidentalis*, *b*, *Liriodendron Tulipifera*, } Tangential sections

In all the illustrations the following lettering is used :
W F—Woody Fibre.
D—Duct.
M R—Medullary Ray.

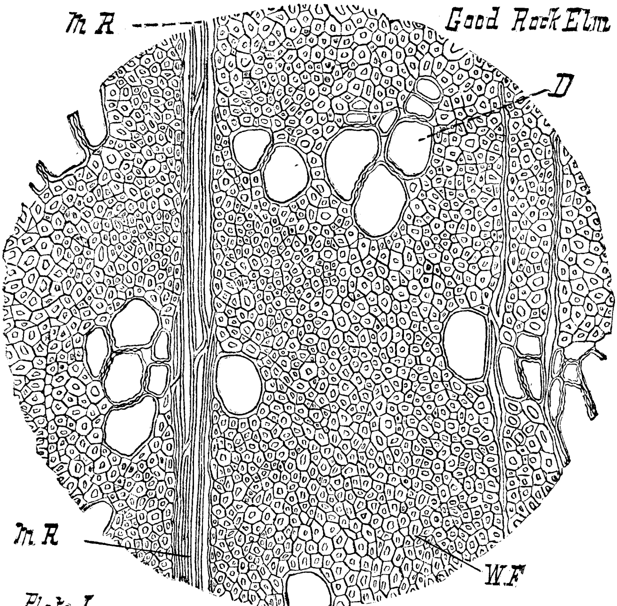
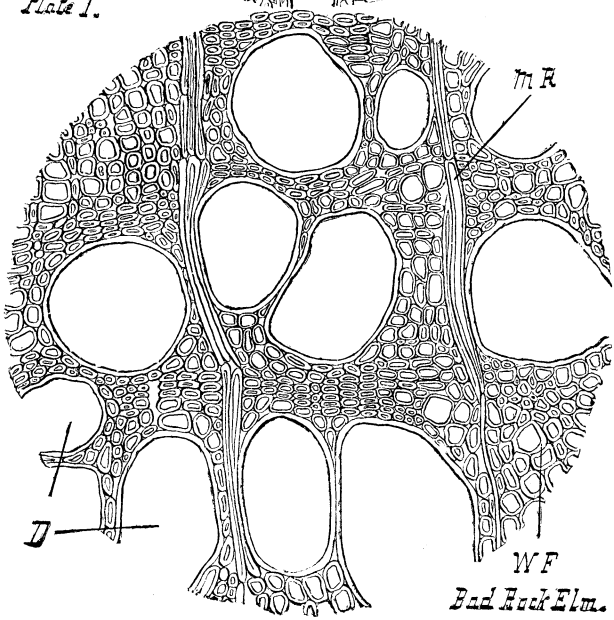
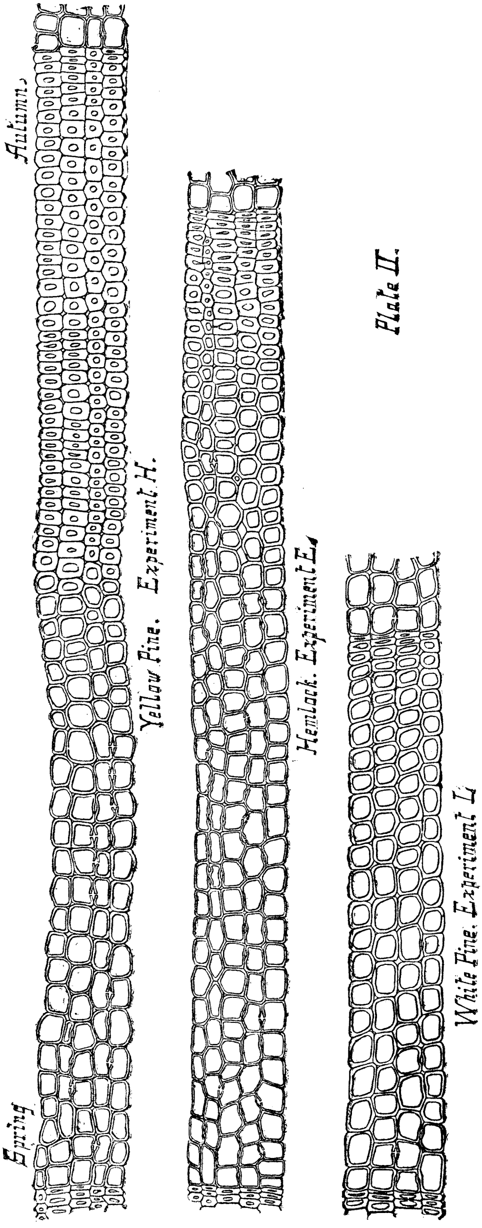
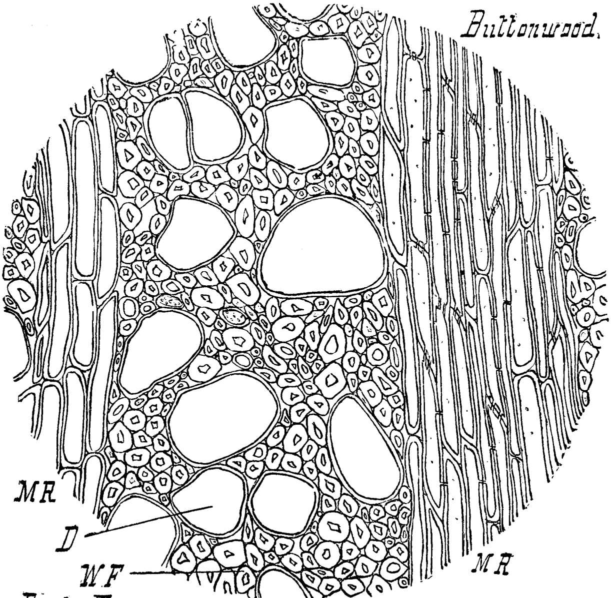


Plate I.

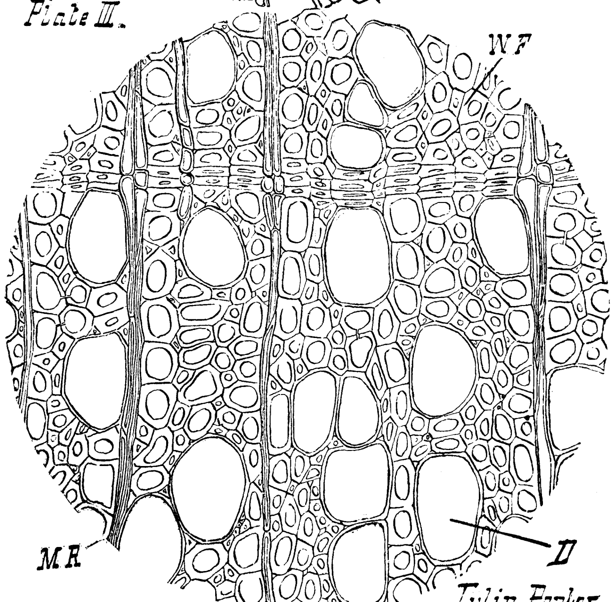



Autumn.
Spring
Yellow Pine. Experiment H.
Hemlock. Experiment E.
White Pine. Experiment L.
Plate II.



Buttonwood.

Plate III.



Tulip Poplar.

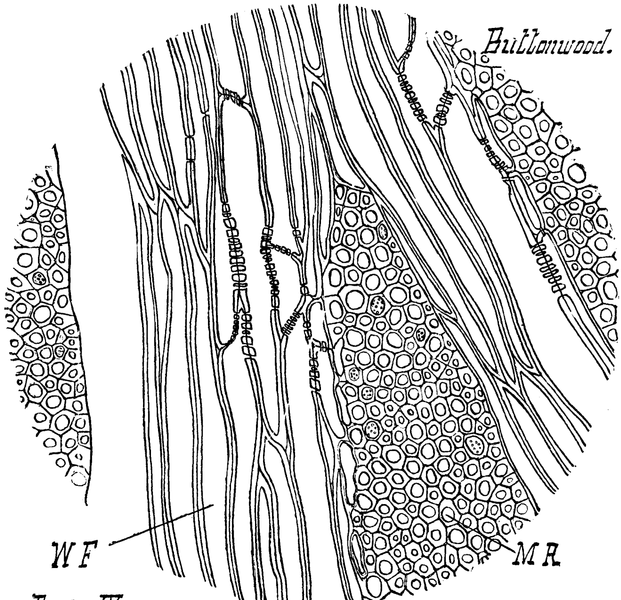


Plate IV